

On the role of the final state interactions in rare B-decays

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Abstract

The effects of final state interactions (FSI) in hadronic B-decays are investigated. The model for FSI, based on Regge phenomenology of high-energy hadronic interactions is proposed. It is shown that this model explains the pattern of phases in matrix elements of $B \rightarrow \pi\pi$ and $B \rightarrow \rho\rho$ decays. These phases play an important role for CP-violation in B-decays. The most precise determination of the unitarity triangle angle α from $B_d \rightarrow \rho\pi$ decays is performed. The relation between CP-asymmetries in $B \rightarrow K\pi$ decays is discussed. It is emphasized that the large distance FSI can explain the structure of polarizations of the vector mesons in B-decays and other puzzles like a very large branching ratio of the B-decay to $\bar{\Xi}_c\Lambda_c$.

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1 Introduction

In this paper we give a review of some unusual properties of the matrix elements in the hadronic B-decays. It is based on papers [1, 2], where $B \rightarrow \pi\pi$, $B \rightarrow \rho\rho$ decays were discussed and it contains some new material on $B \rightarrow \rho\pi$, $B \rightarrow K\pi$ decays and polarization of vector mesons in B-decays. The detailed information on B-decays, obtained in the experiments at B-factories [3], provides a testing ground for theoretical models. The investigation of rare B-decays and CP violation in these decays provides not only the information on CKM matrix, but also on QCD dynamics both at small and large distances.

One of the most interesting and unsolved problems in B-decays is the role of FSI. In this paper we shall demonstrate that FSI play an important role in the hadronic B-decays and enable to explain some puzzles observed in rare B-decays. In particular it will be demonstrated that the phases due to strong interactions are substantial in some hadronic B-decays. These phases are important for understanding the pattern of CP-violation in rare B-decays. The model for calculation of FSI will be formulated and compared to the data on $B \rightarrow \pi\pi$ and $B \rightarrow \rho\rho$ decays. The model is based on Regge-picture for high-energy binary amplitudes and enables to explain a pattern of helicity amplitudes in some B-decays to vector mesons. The large distance interactions provide a simple explanation of the anomalously large branching ratio of the B-decay to $\bar{\Xi}_c\Lambda_c$. The CP-violation asymmetries

will be discussed and the most accurate determination of the unitarity triangle angle α will be presented.

2 $B \rightarrow \pi\pi/B \rightarrow \rho\rho$ puzzle

The probabilities of three $B \rightarrow \pi\pi$ and three $B \rightarrow \rho\rho$ decays are measured now with a good accuracy and presented in Table I. There is a large difference between the ratios of the charged averaged B_d decay probabilities to the charged and neutral mesons:

$$R_\rho \equiv \frac{\text{Br}(B_d \rightarrow \rho^+ \rho^-)}{\text{Br}(B_d \rightarrow \rho^0 \rho^0)} \approx 35, \quad R_\pi \equiv \frac{\text{Br}(B_d \rightarrow \pi^+ \pi^-)}{\text{Br}(B_d \rightarrow \pi^0 \pi^0)} \approx 4. \quad (1)$$

It was demonstrated in refs.[1, 2] that this difference is related to the difference of phases due to strong interactions for matrix elements of $B \rightarrow \pi\pi$ and $B \rightarrow \rho\rho$ -decays. The matrix elements of these decays can be expressed in terms of amplitudes with isospin zero and two. To take into account the differences in CKM phases for tree and penguin contributions we separate the amplitude with $I=0$ into the corresponding parts A_0 and P :

$$\begin{aligned} M_{\bar{B}_d \rightarrow \pi^+ \pi^-} &= \frac{G_F}{\sqrt{2}} |V_{ub} V_{ud}^*| m_B^2 f_\pi f_+(0) \left\{ e^{-i\gamma} \frac{1}{2\sqrt{3}} A_2 e^{i\delta_2^\pi} + \right. \\ &\quad \left. + e^{-i\gamma} \frac{1}{\sqrt{6}} A_0 e^{i\delta_0^\pi} + \left| \frac{V_{td}^* V_{tb}}{V_{ub} V_{ud}^*} \right| e^{i\beta} P e^{i(\delta_P^\pi + \bar{\delta}_0^\pi)} \right\}, \end{aligned} \quad (2)$$

$$\begin{aligned} M_{\bar{B}_d \rightarrow \pi^0 \pi^0} &= \frac{G_F}{\sqrt{2}} |V_{ub} V_{ud}^*| m_B^2 f_\pi f_+(0) \left\{ e^{-i\gamma} \frac{1}{\sqrt{3}} A_2 e^{i\delta_2^\pi} - \right. \\ &\quad \left. - e^{-i\gamma} \frac{1}{\sqrt{6}} A_0 e^{i\delta_0^\pi} - \left| \frac{V_{td}^* V_{tb}}{V_{ub} V_{ud}^*} \right| e^{i\beta} P e^{i(\delta_P^\pi + \bar{\delta}_0^\pi)} \right\}, \end{aligned} \quad (3)$$

$$M_{\bar{B}_u \rightarrow \pi^- \pi^0} = \frac{G_F}{\sqrt{2}} |V_{ub} V_{ud}^*| m_B^2 f_\pi f_+(0) \left\{ \frac{\sqrt{3}}{2\sqrt{2}} e^{-i\gamma} A_2 e^{i\delta_2^\pi} \right\}, \quad (4)$$

where V_{ik} are the elements of CKM matrix, γ and β are the unitarity triangle angles and we factor out the product $m_B^2 f_\pi f_+(0)$ which appears when the decay amplitudes are calculated in the factorization approximation.

The charge conjugate amplitudes are obtained by the same formulas with substitution $\beta, \gamma \rightarrow -\beta, -\gamma$.

The CP asymmetries are given by [4]:

$$C_{\pi\pi} \equiv \frac{1 - |\lambda_{\pi\pi}|^2}{1 + |\lambda_{\pi\pi}|^2}, \quad S_{\pi\pi} \equiv \frac{2\text{Im}(\lambda_{\pi\pi})}{1 + |\lambda_{\pi\pi}|^2}, \quad \lambda_{\pi\pi} \equiv e^{-2i\beta} \frac{M_{\bar{B} \rightarrow \pi\pi}}{M_{B \rightarrow \pi\pi}},$$

where $\pi\pi$ is $\pi^+ \pi^-$ or $\pi^0 \pi^0$.

The analogous formulas take place for $\rho\rho$ final states where the longitudinal polarizations of ρ -mesons are dominant.

The values of P can be determined using $d \leftrightarrow s$ interchange symmetry from decays $B_u \rightarrow K^{0*} \rho^+$ and $B_u \rightarrow K^0 \pi^+$ [5] and turn out to be rather small compared to tree contributions. Note, however, that P determines the magnitudes of the direct CP violation in hadronic decays.

If we neglect the penguin contribution, then the difference of phases is expressed in terms of the branching ratios as follows

$$\cos(\delta_0^\pi - \delta_2^\pi) = \frac{\sqrt{3}}{4} \frac{B_{+-} - 2B_{00} + \frac{2}{3}\frac{\tau_0}{\tau_+}B_{+0}}{\sqrt{\frac{\tau_0}{\tau_+}B_{+0}}\sqrt{B_{+-} + B_{00} - \frac{2}{3}\frac{\tau_0}{\tau_+}B_{+0}}} . \quad (5)$$

Using the experimental information on the branching ratios of $B \rightarrow \pi\pi$ -decays [3] we obtain $|\delta_0^\pi - \delta_2^\pi| = 48^\circ$.

The penguin contributions to B_{ik} do not interfere with the tree ones because CKM angle $\alpha = \pi - \beta - \gamma$ is almost equal to $\pi/2$. Taking into account P-term we get:

$$|\delta_0^\pi - \delta_2^\pi| = 37^\circ \pm 10^\circ . \quad (6)$$

This agrees with the result of the analysis in ref.[6]:

$$\delta_0^\pi - \delta_2^\pi = 40^\circ \pm 7^\circ . \quad (7)$$

Thus the difference of the phases of the matrix elements with $I=0$ and $I=2$ is not small in sharp contrast with the factorization approximation often used for estimates of heavy meson decays.

For $B \rightarrow \rho\rho$ -decays we obtain in the analogous way:

$$|\delta_0^\rho - \delta_2^\rho| = 11^{+6^\circ}_{-11^\circ} . \quad (8)$$

This phase difference is smaller than for pions and is consistent with zero.

The fact that the phases due to FSI are in general not small for heavy quark decays is confirmed by the other D and B-decays. The data on $D \rightarrow \pi^+\pi^-$, $D \rightarrow \pi^0\pi^0$ and $D^\pm \rightarrow \pi^\pm\pi^0$ branching ratios lead to [7]:

$$\delta_2^D - \delta_0^D \equiv \delta_D = \pm(86^\circ \pm 4^\circ) . \quad (9)$$

The last example is $B \rightarrow D\pi$ decays. $D\pi$ pair produced in B -decays can have $I = 1/2$ or $3/2$. From the measurement of the probabilities of $B^- \rightarrow D^0\pi^-$, $B^0 \rightarrow D^-\pi^+$ and $B^0 \rightarrow D^0\pi^0$ decays in paper [8] the FSI phase difference of these two amplitudes was determined:

$$\delta_{D\pi} = 29^\circ \pm 4^\circ . \quad (10)$$

Thus the experimental data indicate that the phases due to FSI are not small for heavy meson decays.

3 Calculation of the FSI phases of $B \rightarrow \pi\pi$ and $B \rightarrow \rho\rho$ decay amplitudes

Let us remind that for $K \rightarrow \pi\pi$ decays there are no inelastic channels, Migdal-Watson (MW) theorem is applicable and strong interaction phases of S -matrix elements of $K \rightarrow (2\pi)_I$ decays are equal to the phases of the corresponding $\pi\pi \rightarrow \pi\pi$ scattering amplitudes at $E = m_K$.

For B-mesons there are many opened inelastic channels and MW theorem is not directly applicable. Serious arguments that strong phases should disappear in the $M_Q \rightarrow \infty$ limit

were given by J.D. Bjorken [9]. He emphasized the fact that the characteristic configurations of the light quarks produced in the decay have small size $\sim 1/M_Q$ and FSI interaction cross sections should decrease as $1/M_Q^2$. Similar arguments were applied in the analysis of heavy quark decays in the QCD perturbation theory [10]. These arguments can be applied to the total hadronic decay rates. For individual decay channels (like $B \rightarrow \pi\pi$) which are suppressed in the limit $M_Q \rightarrow \infty$ the situation is more delicate. However, even in these situations the arguments of Bjorken that due to large formation times the final particles are formed and can interact only at large distances from the point of the decay seem relevant.

On the other hand, the formal analysis of different classes of Feynman diagrams, including soft rescatterings [11, 12], show that the diagrams with pomeron exchange in the FSI-amplitudes do not decrease as M_Q increases. The same conclusions follow from the applications of generalizations of MW-theorem [13, 14].

In the process of the analysis of FSI in heavy meson decays it is important to understand the structure of the intermediate multiparticle states. It was shown in ref.[2] that the bulk of multiparticle states produced in heavy meson decays has a small probability to transform into two-meson final state and only quasi two-particle intermediate states XY with the masses $M_{X(Y)}^2 \leq M_B \Lambda_{QCD} \ll M_B^2$ can be effectively transformed into the final two-meson state. In refs.[1, 2] in calculation of FSI effects for $B \rightarrow \pi\pi$ and $B \rightarrow \rho\rho$ decays only two particle intermediate states with positive G -parity to which B -mesons have relatively large decay probabilities were considered. Alongside with $\pi\pi$ and $\rho\rho$ there is only one such state: πa_1 .

We shall use Feynman diagrams approach to calculate FSI phases from the diagram with the low mass intermediate states X and Y . Integrating over loop momenta d^4k one can transform the integral over k_0 and k_z into the integral over the invariant masses of clusters of intermediate particles X and Y :

$$\int dk_0 dk_z = \frac{1}{2M_B^2} \int ds_X ds_Y , \quad (11)$$

and deform integration contours in such a way that only the low mass intermediate states contributions are taken into account while the contribution of heavy states being small is neglected. In this way we get:

$$M_{\pi\pi}^I = M_{XY}^{(0)I} (\delta_{\pi X} \delta_{\pi Y} + iT_{XY \rightarrow \pi\pi}^{J=0}) , \quad (12)$$

where $M_{XY}^{(0)I}$ are the decay matrix elements without FSI interactions and $T_{XY \rightarrow \pi\pi}^{J=0}$ is the $J = 0$ partial wave amplitude of the process $XY \rightarrow \pi\pi$ ($T^J = (S^J - 1)/(2i)$) which originates from the integral over d^2k_\perp .

For real T Eq.(12) coincides with the application of the unitarity condition for the calculation of the imaginary part of M while for the imaginary T the corrections to the real part of M are generated.

This approach is analogous to the FSI calculations performed in paper [15]. In [15] $2 \rightarrow 2$ scattering amplitudes were considered to be due to elementary particle exchanges in the t -channel. For vector particle exchanges s -channel partial wave amplitudes behave as $s^{J-1} \sim s^0$ and thus do not decrease with energy (decaying meson mass). However it is well known that the correct behavior is given by Regge theory: $s^{\alpha_i(0)-1}$. For ρ -exchange $\alpha_\rho(0) \approx 1/2$ and the amplitude decrease with energy as $1/\sqrt{s}$. This effect is very spectacular for $B \rightarrow DD \rightarrow \pi\pi$ chain with $D^*(D_2^*)$ exchange in t -channel: $\alpha_{D^*}(0) \approx -1$ and reggeized D^* meson exchange is damped as $s^{-2} \approx 10^{-3}$ in comparison with the elementary D^* exchange

(see for example [14]). For π -exchange, which gives a dominant contribution to $\rho\rho \rightarrow \pi\pi$ transition (see below), in the small t region the pion is close to mass shell and its reggeization is not important.

Note that the pomeron contribution does not decrease for $M_Q \rightarrow \infty$, however it does not contribute to the difference of phases $\delta_0^\pi - \delta_2^\pi$ which we are interested in. So this phase difference is determined by the secondary exchanges (ρ, π) and it decreases at least as $1/M_Q$ for large M_Q in accordance with Bjorken arguments. For phases δ_0^π and δ_2^π separately the pomeron contribution does not cancel in general. If Bjorken arguments are valid for these quantities it can happen only under exact cancellation of different diffractively produced intermediate states and it does not happen in the model of refs.[1, 2].

Let us calculate the imaginary parts of $B \rightarrow \pi\pi$ decay amplitudes which originate from $B \rightarrow \rho\rho \rightarrow \pi\pi$ chain :

$$\text{Im}M(B \rightarrow \pi\pi) = \int \frac{d\cos\theta}{32\pi} M(\rho\rho \rightarrow \pi\pi) M^*(B \rightarrow \rho\rho) . \quad (13)$$

In the amplitude $\rho\rho \rightarrow \pi\pi$ of $\rho\rho$ intermediate state the exchange by pion trajectory in the t -channel dominates. It was already stressed that ρ -mesons produced in B -decays are almost entirely longitudinally polarized. That is why it is necessary to take into account only longitudinal polarizations for the intermediate ρ -mesons. The amplitude of $\rho^+\rho^0 \rightarrow \pi^0\pi^+$ transition is determined by the well known constant $g_{\rho\rightarrow\pi\pi}$. This contribution is the dominant one for $B \rightarrow \pi\pi$ decays due to a large probability of $B \rightarrow \rho\rho$ -transition. Let us note that in the limit $M_B \rightarrow \infty$ the ratio $\text{Br}(B_d \rightarrow \rho\rho)/\text{Br}(B_d \rightarrow \pi\pi)$ grows as M_B^2 , that is why FSI phase $\delta_2^\pi(\rho\rho)$ (and $\delta_0^\pi(\rho\rho)$) diminishes only as $1/M_B$. On the contrary $\pi\pi$ intermediate state plays a minor role in $B \rightarrow \rho\rho$ -decays.

In description of $\pi\pi$ elastic scattering amplitudes in Eq.(12) the contributions of P, f and ρ Regge-poles were taken from ref.[16]. Finally πa_1 intermediate state should be taken into account. The large branching ratio of $B_d \rightarrow \pi^\pm a_1^\mp$ -decay ($\text{Br}(B_d \rightarrow \pi^\pm a_1^\mp) = (40 \pm 4) * 10^{-6}$) is partially compensated by the small $\rho\pi a_1$ coupling constant (it is $1/3$ of $\rho\pi\pi$ one). As a result the contribution of πa_1 intermediate state (which transforms into $\pi\pi$ by ρ -trajectory exchange in the t -channel) to FSI phases equals approximately that part of $\pi\pi$ intermediate state contribution which is due to ρ -trajectory exchange. Assuming that the sign of the πa_1 intermediate state contribution to phases is the same as that of the elastic channel and taking into account that the loop corrections to $B \rightarrow \pi\pi$ decay amplitudes lead to the diminishing of the (real) tree amplitudes by $\approx 30\%$ we obtain:

$$\delta_0^\pi = 30^\circ, \quad \delta_2^\pi = -10^\circ, \quad \delta_0^\pi - \delta_2^\pi = 40^\circ . \quad (14)$$

The accuracy of this prediction is about 15° .

For $\rho\rho$ final state the analogous difference is about three times smaller, $\delta_0^\rho - \delta_2^\rho \approx 15^\circ$. Thus the proposed model for FSI enables us to explain the $B \rightarrow \pi\pi/B \rightarrow \rho\rho$ puzzle.

4 Direct CPV in $B \rightarrow \pi\pi$ -decays and phases of the penguin contribution

It follows from Eq. (2) that the direct CP asymmetry in $B_d(\bar{B}_d) \rightarrow \pi^+\pi^-$ decay has the following expression in terms of quantities A_0, A_2, P and phases:

$$C_{+-} = -\frac{\tilde{P}}{\sqrt{3}} \sin\alpha [\sqrt{2}A_0 \sin(\delta_0 - \tilde{\delta}_0 - \delta_P) + A_2 \sin(\delta_2 - \tilde{\delta}_0 - \delta_P)]/$$

$$\begin{aligned}
& / \left[\frac{A_0^2}{6} + \frac{A_2^2}{12} + \frac{A_0 A_2}{3\sqrt{2}} \cos(\delta_0 - \delta_2) - \sqrt{\frac{2}{3}} A_0 \tilde{P} \cos \alpha \cos(\delta_0 - \tilde{\delta}_0 - \delta_P) - \right. \\
& \left. - \frac{A_2 \tilde{P}}{\sqrt{3}} \cos \alpha \cos(\delta_2 - \tilde{\delta}_0 - \delta_P) + \tilde{P}^2 \right] , \tag{15}
\end{aligned}$$

where

$$\tilde{P} \equiv \left| \frac{V_{td}^* V_{tb}}{V_{ub} V_{ud}^*} \right| P . \tag{16}$$

Thus the direct CP-violation parameter is proportional to the modulus of the penguin amplitude and is sensitive to the difference of the strong phases of A_0, A_2 and penguin amplitudes. So far we have discussed the phases of the amplitudes A_0, A_2 . The penguin diagram contains a c -quark loop and has a nonzero phase even in the QCD perturbation theory. It was estimated in ref.[1] and is about 10° . Note that in PQCD it has a positive sign.

Let us estimate the phase of the penguin amplitude δ_P^π considering the charmed mesons intermediate states: $B \rightarrow \bar{D}D, \bar{D}^*D, \bar{D}D^*, \bar{D}^*D^* \rightarrow \pi\pi$. In Regge model all these amplitudes are described at high energies by the exchanges of $D^*(D_2^*)$ -trajectories. An intercept of these exchange-degenerate trajectories can be obtained using the method of [17] or from the masses of $D^*(2007) - 1^-$ and $D_2^*(2460) - 2^+$ resonances, assuming linearity of these Regge-trajectories. Both methods give $\alpha_{D^*}(0) = -0.8 \div -1$ and the slope $\alpha'_{D^*} \approx 0.5 \text{ GeV}^{-2}$.

The amplitude of $D^+D^- \rightarrow \pi^+\pi^-$ reaction in the Regge model proposed in paper [18] can be written in the following form:

$$T_{D\bar{D} \rightarrow \pi\pi}(s, t) = -\frac{g_0^2}{2} e^{-i\pi\alpha(t)} \Gamma(1 - \alpha_{D^*}(t)) (s/s_{cd})^{\alpha_{D^*}(t)} , \tag{17}$$

where $\Gamma(x)$ is the gamma function.

The t -dependence of Regge-residues is chosen in accordance with the dual models and is tested for light (u,d,s) quarks. According to [18] $s_{cd} \approx 2.2 \text{ GeV}^2$.

Note that the sign of the amplitude is fixed by the unitarity in the t -channel (close to the D^* -resonance). The constant g_0^2 is determined by the width of the $D^* \rightarrow D\pi$ decay: $g_0^2/(16\pi) = 6.6$. Using eq.(9) and the branching ratio $Br(B \rightarrow D\bar{D}) \approx 2 \cdot 10^{-4}$ we obtain the imaginary part of P and comparing it with the contribution of P in $B \rightarrow \pi^+\pi^-$ decay probability we get $\delta_P^\pi \approx -3.5^\circ$. The sign of δ_P is negative - opposite to the positive sign which was obtained in perturbation theory. Since $D\bar{D}$ -decay channel constitutes only $\approx 10\%$ of all two-body charm-anticharm decays of B_d -meson, taking these channels into account we easily get

$$\delta_P \sim -10^\circ , \tag{18}$$

which may be very important for the interpretation of the experimental data on direct CP asymmetry.

It was shown in ref.[2] that assuming that the phases satisfy the conditions: $\delta_0 - \delta_2 = 37^\circ, \delta_2 \leq 0$ and $\delta_P > 0$, it is possible to obtain the following inequality

$$C_{+-} > -0.18 . \tag{19}$$

It is worthwhile to compare the obtained numbers with the value of C_{+-} which follows from the asymmetry $A_{CP}(K^+\pi^-)$ if $d \leftrightarrow s$ symmetry is supposed [19]:

$$\begin{aligned}
C_{+-} &= \left(\frac{f_\pi}{f_K} \right)^2 A_{CP}(K^+\pi^-) \frac{\Gamma(B \rightarrow K^+\pi^-) \sin(\beta + \gamma)}{\Gamma(B \rightarrow \pi^+\pi^-) \sin(\gamma)} \left| \frac{V_{td}}{V_{ts}\lambda} \right| = \\
&= 1.2^{(-2)}(-0.093 \pm 0.015) \frac{19.8 \sin 82^\circ}{5.2 \sin 60^\circ} 0.87 = -0.24 \pm 0.04 .
\end{aligned} \tag{20}$$

Experimental results obtained by Belle [20] and BABAR [21] are contradictory:

$$C_{+-}^{Belle} = -0.55(0.09) , C_{+-}^{BABAR} = -0.21(0.09), \tag{21}$$

with Belle number being far below (19). For a non-perturbative phase of the penguin contribution (18) the value of the theoretical prediction for C_{+-} can be made substantially smaller and closer to the Belle result.

For direct CP asymmetry in $B_d(\bar{B}_d) \rightarrow \pi^0\pi^0$ decay from (30) we readily obtain:

$$\begin{aligned}
C_{00} &= -\sqrt{\frac{2}{3}}\tilde{P} \sin \alpha [A_0 \sin(\delta_0 - \tilde{\delta}_0 - \delta_P) - \sqrt{2}A_2 \sin(\delta_2 - \tilde{\delta}_0 - \delta_P)] / \\
&/ \left[\frac{A_0^2}{6} + \frac{A_2^2}{3} - \frac{\sqrt{2}}{3}A_0A_2 \cos(\delta_0 - \delta_2) - \sqrt{\frac{2}{3}}A_0\tilde{P} \cos \alpha \cos(\delta_0 - \tilde{\delta}_0 - \delta_P) + \right. \\
&+ \left. \frac{2}{\sqrt{3}}A_2\tilde{P} \cos \alpha \cos(\delta_2 - \tilde{\delta}_0 - \delta_P) + \tilde{P}^2 \right] ,
\end{aligned} \tag{22}$$

$$C_{00} \approx -1.06[0.8 \sin(\delta_0 - \tilde{\delta}_0 - \delta_P) - 1.4 \sin(\delta_2 - \tilde{\delta}_0 - \delta_P)] \approx -0.6 . \tag{23}$$

This unusually large direct CPV (measured by $|C_{00}|$) is intriguing task for future measurements since the present experimental error is too big:

$$C_{00}^{exper} = -0.48(0.32) . \tag{24}$$

Another CPV asymmetry measured in $B_d(\bar{B}_d) \rightarrow \pi\pi$ decays S_{+-} is sensitive to the unitarity triangle angle α . Let us first neglect the penguin contribution. Then from the experimental value $S_{+-}^{exper} = -0.62 \pm 0.09$ [20, 21] we get:

$$\sin 2\alpha^T = S_{+-} , \tag{25}$$

$$\alpha^T = 109^\circ \pm 3^\circ . \tag{26}$$

The penguin shifts the value of α . The accurate formula looks like:

$$\begin{aligned}
S_{+-} &= [\sin 2\alpha \left(\frac{A_0^2}{6} + \frac{A_2^2}{12} + \frac{A_0A_2}{3\sqrt{2}} \cos(\delta_0 - \delta_2) \right) - \\
&- \frac{A_2\tilde{P}}{\sqrt{3}} \sin \alpha \cos(\delta_2 - \tilde{\delta}_0 - \delta_P) - \sqrt{\frac{2}{3}}A_0\tilde{P} \sin \alpha \cos(\delta_0 - \tilde{\delta}_0 - \delta_P)] / \\
&/ \left[\frac{A_0^2}{6} + \frac{A_2^2}{12} + \frac{A_0A_2}{3\sqrt{2}} \cos(\delta_0 - \delta_2) - \sqrt{\frac{2}{3}}A_0\tilde{P} \cos \alpha \cos(\delta_0 - \tilde{\delta}_0 - \delta_P) - \right. \\
&- \left. \frac{A_2\tilde{P}}{\sqrt{3}} \cos \alpha \cos(\delta_2 - \tilde{\delta}_0 - \delta_P) + \tilde{P}^2 \right] .
\end{aligned} \tag{27}$$

The numerical values of α from different B-decays will be given in the next Section.

5 Analysis of $B_d(\bar{B}_d) \rightarrow \rho^\pm \pi^\mp$ decays

The time dependence of these decay probabilities are given by the following formula [4]:

$$\frac{dN(B_d(\bar{B}_d) \rightarrow \rho^\pm \pi^\mp)}{d\Delta t} = (1 \pm A_{\text{CP}}^{\rho\pi}) e^{-t/\tau} \times [1 - q(C_{\rho\pi} \pm \Delta C_{\rho\pi}) \cos(\Delta mt) + q(S_{\rho\pi} \pm \Delta S_{\rho\pi}) \sin(\Delta mt)] , \quad (28)$$

where $q = -1$ corresponds to the decay of a particle which was B_d at $t = 0$, while $q = 1$ corresponds to the decay of a particle which was \bar{B}_d at $t = 0$. According to [4]:

$$A_{\text{CP}}^{\rho\pi} = \frac{|A^{+-}|^2 - |\bar{A}^{-+}|^2 + |\bar{A}^{+-}|^2 - |A^{-+}|^2}{|A^{+-}|^2 + |\bar{A}^{-+}|^2 + |\bar{A}^{+-}|^2 + |A^{-+}|^2} , \quad (29)$$

where $A^{\pm\mp}$ are the amplitudes of $B_d \rightarrow \rho^\pm \pi^\mp$ decays, while $\bar{A}^{\pm\mp}$ are the amplitudes of $\bar{B}_d \rightarrow \rho^\pm \pi^\mp$ decays. Introducing the ratios of the decay amplitudes:

$$\lambda^{\pm\mp} = \frac{q}{p} \frac{\bar{A}^{\pm\mp}}{A^{\pm\mp}} , \quad (30)$$

where $q/p = e^{-2i\beta}$ comes from $B_d - \bar{B}_d$ mixing and β is the angle of the unitarity triangle, we obtain the expressions for the remaining parameters entering Eq. (28):

$$C_{\rho\pi} \pm \Delta C_{\rho\pi} = \frac{1 - |\lambda^{\pm\mp}|^2}{1 + |\lambda^{\pm\mp}|^2} , \quad S_{\rho\pi} \pm \Delta S_{\rho\pi} = \frac{2\text{Im}\lambda^{\pm\mp}}{1 + |\lambda^{\pm\mp}|^2} , \quad (31)$$

where $C_{\rho\pi}$ and $S_{\rho\pi}$ (as well as $A_{\text{CP}}^{\rho\pi}$) are CP-odd observables, while $\Delta C_{\rho\pi}$ and $\Delta S_{\rho\pi}$ are CP-even. The experimental data for the observables entering Eq. (28) accompanied by the averaged branching fraction are presented in Table 2 [3].

The decay amplitudes $\bar{A}^{\pm\mp}$ are described by the tree and penguin Feynman diagrams shown in Fig.1. The analogous diagrams describe amplitudes $A^{\pm\mp}$. The corresponding formulas for the amplitudes look like:

$$\begin{aligned} \bar{A}^{-+} &= A_1 e^{-i\gamma} + P_1 e^{i(\beta+\delta_1)} , \\ A^{-+} &= A_2 e^{i\gamma} + P_2 e^{-i(\beta-\delta_2)} , \\ \bar{A}^{+-} &= A_2 e^{-i\gamma} + P_2 e^{i(\beta+\delta_2)} , \\ A^{+-} &= A_1 e^{i\gamma} + P_1 e^{-i(\beta-\delta_1)} , \\ A_1/A_2 &\equiv a_1/a_2 e^{i\tilde{\delta}} , \\ P_1/P_2 &\equiv p_1/p_2 e^{i\tilde{\delta}} , \end{aligned} \quad (32)$$

where γ and β are the angles of the unitarity triangle, while δ_1 and δ_2 are the difference of FSI strong phases between penguin and tree amplitudes (for penguin amplitudes we use the so-called t -convention, subtracting charm quark contribution to penguin amplitudes).

All in all we have seven parameters in Eq.(32) specific for $\rho\pi$ final states ($a_1, a_2, p_1, p_2, \delta_1, \delta_2$ and $\tilde{\delta}$) plus UT angle $\alpha = \pi - \beta - \gamma$, while the number of the experimental observables in Table 1 is six. To go further we should involve additional theoretical information in order to reduce the number of parameters. If we find the values of p_1 and p_2 even with considerable

uncertainties it will be very helpful for determination of UT angle α , since penguin amplitudes shift α by small amount proportional to p_i/a_i , and even large uncertainty in this shift leads to few degrees (theoretical) uncertainty in α (see below).

The most straightforward way is to calculate the matrix elements of the corresponding weak interactions Lagrangian with the help of factorization, as it was done in [22]. However it was shown above that there are substantial deviations from factorization in $B \rightarrow \pi\pi$ decays. In particular from the experimental data on direct CP-asymmetry in $B_d(\bar{B}_d) \rightarrow \pi^+\pi^-$ decays we know that the factorization strongly underestimates the contribution of a penguin diagram to the decay amplitude [1, 2]. Another approach is to extract the penguin amplitudes from the branching ratios of the $B^- \rightarrow \bar{K}^{0*}\pi^+$ and $B^- \rightarrow \bar{K}^0\rho^+$ decays in which the penguin dominates with the help of $s \leftrightarrow d$ quark interchange symmetry, analogously to what was done for penguins in $B \rightarrow \pi\pi$ [23] and $B \rightarrow \rho\rho$ [24] decays.

Feynman diagrams responsible for these decays are shown in Fig. 2. Comparing Fig. 2 with Fig. 1 (b) we readily get the following relations:

$$\begin{aligned} Br(\bar{B}_d \rightarrow \pi^+\rho^-)_{P_1} &= \frac{\tau_{B_d}}{\tau_{B_u}} Br(B^- \rightarrow \bar{K}^{0*}\pi^-) \left| \frac{V_{td}}{V_{ts}} \right|^2 = \\ &= \frac{1}{1.071} (10.7 \pm 0.8) \cdot 10^{-6} \cdot (0.20)^2 = 0.40(4) \cdot 10^{-6} , \end{aligned} \quad (33)$$

$$\begin{aligned} Br(\bar{B}_d \rightarrow \rho^+\pi^-)_{P_2} &= \frac{\tau_{B_d}}{\tau_{B_u}} Br(B^- \rightarrow \bar{K}^0\rho^-) \left| \frac{V_{td}}{V_{ts}} \right|^2 = \\ &= \frac{1}{1.071} (8.0 \pm 1.5) \cdot 10^{-6} \cdot (0.20)^2 = 0.30(6) \cdot 10^{-6} , \end{aligned} \quad (34)$$

from which the values of p_1 and p_2 follow:

$$p_1^2 = 0.40(4) \cdot 10^{-6} , \quad p_2^2 = 0.30(6) \cdot 10^{-6} , \quad (35)$$

where here and below we neglect the common factor $16\pi m_B \Gamma_{B_d}$, to which squares of amplitudes are proportional. The remaining $8 - 2 = 6$ parameters entering Eq.(32) we will determine from six experimental numbers presented in Table 2.

From Eq.(32) we get the following relation for the averaged branching ratio of $B_d(\bar{B}_d)$ decays to $\rho^\pm\pi^\mp$:

$$\frac{a_1^2 + a_2^2}{2} + \frac{p_1^2 + p_2^2}{2} = 23.1(2.7) \cdot 10^{-6} , \quad (36)$$

where the penguin-tree interference terms are omitted (being proportional to $\cos(\pi - \beta - \gamma) = \cos \alpha$ they are very small since UT is almost rectangular, $\alpha \approx \pi/2$).

To determine the values of a_i the equation for $\Delta C_{\rho\pi}$ is helpful:

$$\Delta C_{\rho\pi} = \frac{a_1^2 - a_2^2}{a_1^2 + a_2^2} + O\left(\frac{p_i^2}{a_i^2}\right) , \quad (37)$$

and from (35) - (37) and the experimental value for $\Delta C_{\rho\pi}$ from Table 1 we get:

$$a_1^2 = 31(3) \cdot 10^{-6} , \quad a_2^2 = 14(3) \cdot 10^{-6} . \quad (38)$$

Now from the equations for $C_{\rho\pi}$ and $A_{\text{CP}}^{\rho\pi}$ using the experimental data from Table 1 we are able to extract FSI phases δ_1 and δ_2 :

$$\begin{aligned} C_{\rho\pi} &= \frac{2p_1a_1 \sin \delta_1 + 2p_2a_2 \sin \delta_2}{a_1^2 + a_2^2} + \frac{a_1^2 - a_2^2}{(a_1^2 + a_2^2)^2} [2p_2a_2 \sin \delta_2 - 2p_1a_1 \sin \delta_1] , \\ A_{\text{CP}}^{\rho\pi} &= \frac{2p_1a_1 \sin \delta_1 - 2p_2a_2 \sin \delta_2}{a_1^2 + a_2^2} , \end{aligned} \quad (39)$$

$$\sin \delta_1 = -0.55(30) , \quad \sin \delta_2 = 0.51(40) , \quad (40)$$

and we see that large experimental errors of $C_{\rho\pi}$ and $A_{\text{CP}}^{\rho\pi}$ do not allow the accurate determination of the values of FSI phases.

From the equations for S and ΔS we will determine the values of α and $\tilde{\delta}$:

$$\begin{aligned} S_{\rho\pi} + \Delta S_{\rho\pi} &= \\ = 2 \frac{a_1a_2 \sin(2\alpha - \tilde{\delta}) - p_1a_2 \cos(\delta_1 - \tilde{\delta}) - p_2a_1 \cos(\delta_2 - \tilde{\delta}) + 2p_1a_2 \sin \delta_1 \sin \tilde{\delta}}{a_1^2 + a_2^2 + 2p_1a_1 \sin \delta_1 - 2p_2a_2 \sin \delta_2} , \end{aligned} \quad (41)$$

$$\begin{aligned} S_{\rho\pi} - \Delta S_{\rho\pi} &= \\ = 2 \frac{a_1a_2 \sin(2\alpha + \tilde{\delta}) - p_2a_1 \cos(\delta_2 + \tilde{\delta}) - p_1a_2 \cos(\delta_1 + \tilde{\delta}) - 2p_2a_1 \sin \delta_2 \sin \tilde{\delta}}{a_1^2 + a_2^2 + 2p_2a_2 \sin \delta_2 - 2p_1a_1 \sin \delta_1} , \end{aligned} \quad (42)$$

where in (small) terms proportional to p_i we have substituted $\alpha = \pi/2$.

Substituting the numerical values for the parameters in the denominators we get:

$$[(6 \pm 4)S_{\rho\pi} - (45 \pm 4)\Delta S_{\rho\pi}]10^{-6} = 2a_1a_2 \sin \tilde{\delta} \cos 2\alpha , \quad (43)$$

$$\begin{aligned} [(45 \pm 4)S_{\rho\pi} - (6 \pm 4)\Delta S_{\rho\pi}]10^{-6} &= 2a_1a_2 \sin 2\alpha \cos \tilde{\delta} - \\ &- 2p_2a_1 \cos(\tilde{\delta} - \delta_2) - 2p_1a_2 \cos(\tilde{\delta} + \delta_1) . \end{aligned} \quad (44)$$

From the first equation we see that $\tilde{\delta}$ equals zero or π with $\pm 5^0$ accuracy. For UT angle α from the second equation neglecting the penguin contributions we obtain:

$$\alpha_{\rho\pi}^T = 90^\circ \pm 3^\circ(\text{exp}) , \quad (45)$$

while taking penguins into account we get:

$$\alpha_{\rho\pi} = 84^\circ \pm 3^\circ(\text{exp}) , \quad (46)$$

where $\delta_1 \approx -30^\circ$ and $\delta_2 \approx 30^\circ$ were used.

Thus penguins shift α by 6° and even assuming 50% accuracy of $d \leftrightarrow s$ symmetry which was used to determine the numerical values of p_i allows us to determine $\alpha_{\rho\pi}$ with theoretical accuracy which equals the experimental one, originating from that in $S_{\rho\pi}$ and pointed out in (46):

$$\alpha_{\rho\pi} = 84^\circ \pm 3^\circ(\text{exp}) \pm 3^\circ(\text{theor}) . \quad (47)$$

The consideration of $B_d(\bar{B}_d) \rightarrow \pi\pi$ decays (see Eqs.(25) - (27)) leads to the following result:

$$\alpha_{\pi\pi} = 88^\circ \pm 4^\circ(\text{exp}) \pm 10^\circ(\text{theor}) , \quad (48)$$

where a relatively large theoretical error is due to big (20°) shift of the tree level value of $\alpha_{\pi\pi}$ by poorly known penguins and this time (unlike in [2]) we suppose 50% theoretical uncertainty in the value of penguin amplitude.

In the case of $B_d(\bar{B}_d) \rightarrow \rho^+\rho^-$ decays penguin shifts the value of α by the same amount as is considered in this paper for $B_d(\bar{B}_d) \rightarrow \rho^\pm\pi^\mp$ decays, so the theoretical uncertainty is the same:

$$\alpha_{\rho\rho} = 87^\circ \pm 5^\circ(\text{exp}) \pm 3^\circ(\text{theor}) , \quad (49)$$

while larger experimental uncertainty is due to that in $S_{\rho\rho}$,

$$S_{\rho\rho} = -0.06 \pm 0.18 , \quad (50)$$

which is twice as big as in $S_{\rho\pi}$.

It is interesting to compare the numerical values (46), (48), (49) with the recent results of the fit of Unitarity Triangle [25, 26]:

$$\alpha^{\text{CKMfitter}} = 88^\circ \pm 6^\circ , \quad (51)$$

$$\alpha^{\text{UTfit}} = 91^\circ \pm 6^\circ . \quad (52)$$

Large New Physics(NP) contribution to $b \rightarrow dg$ penguin could help to avoid large FSI phases since now the enhancement of direct CPV seen in $A_{\text{CP}}^{\rho\pi}$ will originate from closeness of tree level and penguin amplitudes. Also puzzle of large $Br B_d(\bar{B}_d) \rightarrow \pi^0\pi^0$ can be resolved by NP contribution to $b \rightarrow dg$ penguin comparable with SM one recalculated from $B_u \rightarrow K^0\pi^+$ decay. The bound on such contribution comes from the coincidence within the errors of the values of α extracted from $B \rightarrow \pi\pi$, $\rho\pi$ and $\rho\rho$ decays, where the penguin contributions are very different.¹

These are strong arguments in favor of the measurements of the parameters of $B \rightarrow \pi\pi$, $\rho\pi$ and $\rho\rho$ decays with better accuracy, which can be performed at LHCb and Super B factory. A search of NP manifestation by different values of UT angle α extracted from $B \rightarrow \pi\pi$ and $B \rightarrow \pi\rho, \rho\rho$ decays is analogous to the one suggested in [27] through the difference of α extracted from the penguin polluted $B \rightarrow \pi\pi$ decay and from UT analysis based on tree dominated observables V_{cb} and γ .

At the end of this section let us note that the results (48) and (49) were obtained in the analysis based on isotopic invariance of strong interactions from the violation of which the additional uncertainty in α could follow [28]. Fortunately since in the absence of penguin amplitudes the relation $S_{\pi\pi, \rho\rho} = \sin 2\alpha^T$ is free from this type of uncertainty, it is manifested only as several percent correction to the shift of α induced by penguin which is negligible even for $B \rightarrow \pi\pi$ decays.

¹The same argument can be applied against large NP contributions to $b \rightarrow sg$ penguin: if the same NP does not enhance $b \rightarrow dg$ penguin the value of α from $B \rightarrow \pi\pi$ data will be closer to $\alpha_{\pi\pi}^T = 109^\circ$ and disagree with that from $\alpha_{\pi\rho}$ and $\alpha_{\rho\rho}$.

6 Direct CPV in $B \rightarrow \pi K$ decays

Recently Belle has published new results of the measurement of CP asymmetries in $B_d(\bar{B}_d) \rightarrow K^+\pi^-(K^-\pi^+)$ and $B^+(B^-) \rightarrow K^+\pi^0(K^-\pi^0)$ decays [29]:

$$A_{CP}(K^+\pi^-) \equiv \frac{\Gamma(\bar{B}_d \rightarrow K^-\pi^+) - \Gamma(B_d \rightarrow K^+\pi^-)}{\Gamma(\bar{B}_d \rightarrow K^-\pi^+) + \Gamma(B_d \rightarrow K^+\pi^-)} = -0.094(18)(8) \quad , \quad (53)$$

$$A_{CP}(K^+\pi^0) \equiv \frac{\Gamma(B^- \rightarrow K^-\pi^0) - \Gamma(B^+ \rightarrow K^+\pi^0)}{\Gamma(B^- \rightarrow K^-\pi^0) + \Gamma(B^+ \rightarrow K^+\pi^0)} = 0.07(3)(1) \quad . \quad (54)$$

In [29] the 4.5 standard deviations difference of these asymmetries was considered as a paradox in the framework of the Standard Model (see also [30]) which it really were IF one neglected the color suppressed tree quark amplitude. Taking into account QCD penguin diagram and tree diagrams one easily gets the following relation between CP asymmetries [31]:

$$A_{CP}(K^+\pi^-) = A_{CP}(K^+\pi^0) + A_{CP}(K^0\pi^0) \quad , \quad (55)$$

where $A_{CP}(K^0\pi^0)$ is proportional to the color suppressed tree amplitude C . The experimental value of $A_{CP}(K^0\pi^0)$ has large uncertainty:

$$A_{CP}(K^0\pi^0) = -0.14 \pm 0.11 \quad , \quad (56)$$

however with the help of $d \leftrightarrow s$ interchange symmetry it can be related with CP asymmetry C_{00} of $B_d(\bar{B}_d) \rightarrow \pi^0\pi^0$ decays:

$$A_{CP}(K^0\pi^0) = \frac{\Gamma(B_d \rightarrow \pi^0\pi^0) + \Gamma(\bar{B}_d \rightarrow \pi^0\pi^0)}{\Gamma(B_d \rightarrow K^0\pi^0) + \Gamma(\bar{B}_d \rightarrow \bar{K}^0\pi^0)} \left| \frac{V_{us}V_{ts}}{V_{td}} \right| \frac{\sin \gamma}{\sin \alpha} C_{00} \quad , \quad (57)$$

where the opposite signs in the definitions of A_{CP} and C_{00} are compensated by a negative sign of V_{ts} . The experimental uncertainty of C_{00} is also very large, that is why we use the above result (Eq.(23)) for numerical estimate:

$$C_{00} \approx -0.6 \quad . \quad (58)$$

Substituting (58) in (57) and (53), (54) and (57) in (55) we finally obtain:

$$-0.094 \pm 0.02 = (0.07 \pm 0.03) + (-0.07 \pm 0.02) \quad , \quad (59)$$

resolving in this way the paradox noted in [29] (the remaining $\approx 2\sigma$ difference can be safely attributed to statistical fluctuation). Concluding this Section let us remind that the absence of color suppression of the tree amplitude of $B_d \rightarrow \pi^0\pi^0$ decay is explained in Sections 2,3 by large FSI phases difference of tree amplitudes with isospin zero and two.

7 Polarizations of vector mesons in $B \rightarrow VV$ -decays

In this Section we consider $B_d(\bar{B}_d)$ decays into the pair of light (ρ, K^*, φ) vector mesons. The short distance contributions to vector meson production in B-decays lead to the dominance of the longitudinal polarization of the vector mesons. This is a general property valid in the large M_Q - limit due to helicity conservation for vector currents and corrections should be $\sim M_V^2/M_Q^2$. It is satisfied experimentally in $B \rightarrow \rho^+\rho^-$ decays, where the contribution

of longitudinal polarization of ρ mesons is $f_L = \Gamma_L/\Gamma = 0.968 \pm 0.023$. Let us note that FSI are not important for these decays; for example there are no large strong interaction phases generated by rescattering. The manifestation of this statement is the absence of enhancement of the color suppressed amplitude which describes the decay into $\rho^0\rho^0$.

On the other hand there are several B-decays to vector mesons, where the longitudinal polarizations give only about 50% of decay rates. For example:

for $B^+ \rightarrow K^{*0}\rho^+$ $f_L = 0.48 \pm 0.08$, $B_d \rightarrow K^{*0}\rho^0$ $f_L = 0.57 \pm 0.12$, $B^+ \rightarrow \phi K^{*+}$ $f_L = 0.50 \pm 0.07$, $B_d \rightarrow \phi K^{*0}$ $f_L = 0.491 \pm 0.032$ [3].

This is a real puzzle IF only short distance dynamics for these decays is invoked. We would like to argue that strong rescattering related to large distance dynamics may be responsible for the observed polarizations pattern. First let us note that in all the decays, where $f_L \approx 50\%$, the penguin diagrams give dominant contribution. In this case a large contribution to the matrix elements of the decays comes from $DD_s(D^*\bar{D}_s, D\bar{D}_s^*, \dots)$ intermediate states, which have large branching ratios. In Section 4 we analyzed $D\bar{D}$ intermediate state contribution to a strong phase of the penguin amplitude for $B_d(\bar{B}_d) \rightarrow \pi\pi$ decays. It was argued that the phase of the order of 10° can be generated by the charmed mesons intermediate state.² FSI is important due to large branching ratio $\text{Br}(B_d \rightarrow D\bar{D}) \approx 2 \cdot 10^{-4}$ in comparison with the penguin contribution to decays to two pions [2]: $\text{Br}(B \rightarrow \pi\pi)_P = 0.6 \cdot 10^{-6}$ extracted with a help of $d \leftrightarrow s$ symmetry. In the case of $b \rightarrow sg$ penguin dominated decays the intermediate state contains DD_s pair, and we should compare $\text{Br}(B_d \rightarrow DD_s) \approx 10^{-2}$ with $\text{Br}(B \rightarrow K^{*0}\rho^+) \approx 10^{-5}$. That is why the relative contribution of DD_s states are ~ 2 times larger than for $B \rightarrow \pi\pi$ penguins. The amplitude of the binary reaction $D\bar{D}_s \rightarrow VV$ at high energies is dominated by the exchange of D^* -regge trajectory and according to general rules for spin-structure of regge vertices (see for example [32]) the final vector mesons are produced at high energies transversely polarized. Thus we expect a large fraction of transverse polarization of vector mesons in these decays. The value of f_L is sensitive to intercept of D^* -trajectory [33]. If the penguin contribution in the decays indicated above is dominant in the SU(3) limit we have:

$$\text{Br}(\phi K^{*0}) = \text{Br}(K^{*0}\rho^+) = \text{Br}(\phi K^{*+}) = 2\text{Br}(K^{*0}\rho^0) \quad (60)$$

and f_L in all these decays should be the same. These predictions agree with experimental data [3].

8 Puzzle of charm-anticharm baryons production

Large probability of B-decay to $\Lambda_c \bar{\Xi}_c$ has been observed recently: $\text{Br}(B^+ \rightarrow \Lambda_c^+ \bar{\Xi}_c^0) \sim 10^{-3}$ [3]. It is surprisingly large compared to the branching of B-decay to $\Lambda_c^+ \bar{p} = (2.19 \pm 0.8)10^{-5}$. From PQCD point of view both processes are described by similar diagrams with the substitution of $u\bar{d}$ (for \bar{p}) by $c\bar{s}$ (for $\bar{\Xi}_c$) and phase space arguments even favor \bar{p} -production.

On the other hand from the soft rescatterings point of view the large probabilities of $\bar{D}D_s(\bar{D}^*D_s, \bar{D}D_s^*, \dots)$ intermediate states, considered in the previous section, can play an important role in $B^+ \rightarrow \Lambda_c^+ \bar{\Xi}_c^0$ -decays. For $\Lambda_c^+ \bar{p}$ final states the corresponding two-meson intermediate states have smaller branchings and, what is even more important, have different kinematics. For $\bar{D}D_s, \dots$ intermediate states the momentum of these heavy states is not large ($p \approx 1.8 \text{ GeV}$) in B rest frame and all light quarks (u, d, \bar{d}, \bar{s}) are slow in this frame. The final

²Let us emphasize that this considerable contribution to the subdominant penguin amplitude is not important for the $B_d(\bar{B}_d) \rightarrow \pi\pi$ widths, where the tree diagram dominates.

$\Lambda_c^+ \Xi_c^0$ are also rather slow in the B-rest frame and thus all quarks have large projections to the wave functions of the final baryons. On the contrary for $\pi D, \rho D, ..$ intermediate states in $\Lambda_c^+ \bar{p}$ -decays momenta of \bar{u}, d - quarks in light mesons are large and the projections to the wave functions of final baryons have extra smallness. The resulting suppression can be estimated in regge-model of ref.[18] with the nucleon trajectory exchange in the t-channel and is $\sim 10^{-2}$ in accordance with experimental observation.

9 Conclusions

FSI play an important role in two-body hadronic decays of heavy mesons. Theoretical estimates with account of the lowest intermediate states give a satisfactory agreement with the experiment and provide the explanation of several puzzles observed in B decays.

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Table 1

Mode	Br(10^{-6})	Mode	Br(10^{-6})
$B_d \rightarrow \pi^+\pi^-$	5.2 ± 0.2	$B_d \rightarrow \rho^+\rho^-$	24.2 ± 3.2
$B_d \rightarrow \pi^0\pi^0$	1.3 ± 0.2	$B_d \rightarrow \rho^0\rho^0$	0.68 ± 0.27
$B_u \rightarrow \pi^+\pi^0$	5.7 ± 0.4	$B_u \rightarrow \rho^+\rho^0$	18.2 ± 3.0

C -averaged branching ratios of $B \rightarrow \pi\pi$ and $B \rightarrow \rho\rho$ decays.

Table 2

$Br B_d(\bar{B}_d) \rightarrow$ $\rightarrow \rho^\pm \pi^\mp$	$A_{\text{CP}}^{\rho\pi}$	$C_{\rho\pi}$	$\Delta C_{\rho\pi}$	$S_{\rho\pi}$	$\Delta S_{\rho\pi}$
$(23.1 \pm 2.7)10^{-6}$	-0.13 ± 0.04	0.01 ± 0.07	0.37 ± 0.08	0.01 ± 0.09	-0.04 ± 0.10

The experimental values of observables which describe $B_d(\bar{B}_d) \rightarrow \rho^\pm \pi^\mp$ decays.

FIGURES

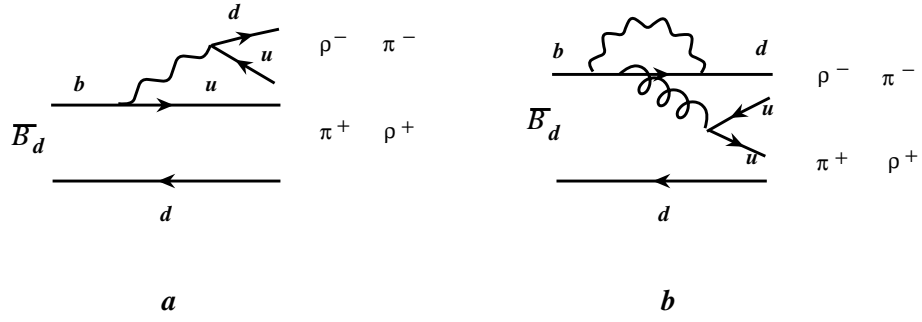


Figure 1: Tree and penguin diagrams for B-decays to $\rho\pi^-$ mesons. $\bar{B}_d \rightarrow \rho^-\pi^+$ decay is described by the amplitudes A_1 and P_1 , while $\bar{B}_d \rightarrow \rho^+\pi^-$ decay - by the amplitudes A_2 and P_2 .

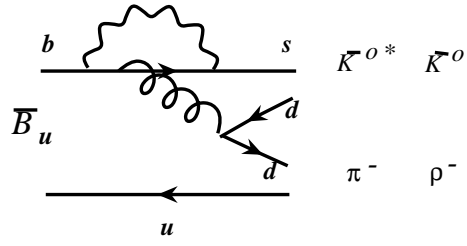


Figure 2: B^- decays in which the penguin diagram dominates.